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COMMENTARY

Exploiting Synergy of Carbon Pricing and Other Policy Instruments for Deep Decarbonization

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Recently, it has been questioned whether carbon pricing is an efficient and effective tool to foster deep decarbonization, culminating in the claim that carbon pricing actually hinders the achievement of such a transformation.[1,2] This criticism disregards what we believe has been the consensus for many years now, namely that the deep decarbonization of our economies essentially requires a comprehensive and disruptive policy package that includes carbon pricing among other measures, such as technology-specific support schemes. Here, we emphasize that carbon pricing could and should be part of any effective policy mix and that some of the arguments against carbon pricing are flawed.

First, one argument often put forward is that carbon pricing and technology-specific instruments differ in the way carbon emission reductions are delivered.[1] Carbon prices at socially acceptable levels trigger emission reductions by the cheapest currently available low(er)-carbon technologies, e.g., by inducing a switch from lignite and coal to natural gas in electricity production. In contrast, technology-specific instruments can be tailored in a way to support technologies that are currently very expensive but that, because of technological and institutional learning, may become cheaper in the long term, thus lowering long-term mitigation costs.[3] Neo-classical economics has taken this discussion into account by acknowledging the role of technological and institutional learning in their models for a long time.[4] A practical example of technological learning is solar photovoltaic (PV) in Germany, where costs decreased by a factor of 10 in less than 20 years as a result of support policies. Yet, success of technology-specific support schemes is far from certain. Expectations on emission reductions from European Union (EU) biofuel mandates, for example, were far too optimistic.[5] In our view, targeted-technology support alone, therefore, is no panacea.

A second argument against carbon pricing is that it is ineffective, *inter alia*, because prices are currently too low.[2] Setting prices higher, however, allegedly would not work because of a lack of social and political acceptance—one of the reasons being that carbon pricing may hit poorer households harder than richer ones. While we agree that distributional impacts of policies matter, we want to emphasize that *any* decarbonization policy will have distributional impacts, and mostly these are going to affect low-income households particularly, as they spend a larger share of their income on energy, compared to richer households. As an example, banning internal combustion engines, a measure proposed by some,[2] would hit low-income rural households hard, as the currently high costs for electric vehicles prohibit substitution. In addition, it remains unclear to us why the acceptance of such policies would be higher than that of increasing carbon prices to effective levels. Importantly, recent events such as the Yellow Vest protests in France

show that climate policies may trigger strong protests if they are not accompanied by significant compensation mechanisms. However, a recent empirical analysis[6] highlights in detail how substantial and targeted-compensation measures could have been implemented in the case of the French carbon tax. Theoretically, the distributional consequences of virtually *any* policy can be counteracted by introducing appropriate compensation measures for losers, such as flat lump-sum transfers or targeted transfers to, e.g., rural households or low-income households.[7] The acceptance of carbon pricing policies will be further affected by factors other than distributional issues, such as political economy constraints, e.g., lobbying by those heavily affected, political trust, and behavioral biases due to different perceptions, values, and beliefs.[8,9] In the real world, carbon pricing schemes—e.g., those in British Columbia, Switzerland, or coal-producing Alberta—have led to the implementation of a diverse mix of compensation measures, such as tax cuts, green investments, flat transfers, and targeted transfers. The need for compensation mechanisms in the case of carbon pricing has thus been widely recognized both in the real world and by economists and should be extended to other decarbonization policies, such as targeted-technology support and command and control instruments.

Third, we see several positive effects of carbon pricing that are not achieved by other policies: it allows harvesting of "low-hanging fruits." While a deep decarbonization requires the picking of "high-hanging fruits" as well,[1] we also see the benefits of carbon pricing in affected sectors, such as power generation. While the carbon price in the EU quadrupled from 2016 to 2018, to hover around 20 €/t, German power generation from hard coal and lignite fell by 12.5% compared to 2016. While some of the decline can be attributed to a *de facto* shutdown of lignite-fired power plants, a higher carbon price, which raises the relative cost of emission-intense generators, likely decreases emissions in the power sector too.[10] Such reductions in carbon emissions buy us additional time to develop the technologies required for full decarbonization, thereby increasing the feasibility of climate change mitigation. Moreover, using technology-specific subsidies first to trigger technological learning when technologies are still very expensive and subsequently introduce carbon pricing, once the cost of these technologies has been significantly reduced, is a way of limiting the impacts on total mitigation costs; it first allows the support of a few high-cost technologies, and after some time, (lower) carbon prices are sufficient to allow the competitive market participation of these technologies.[1] Thus, introducing very high carbon prices can be prevented. In addition, if carbon revenues are recycled, macro-economic impacts will be very low, if not positive, even when one disregards the environmental (co-)benefits from less CO_2 emissions.[7,11]

Fourth, carbon pricing and technology-support instruments differ considerably in their effect on energy consumption. As carbon prices are passed through to energy prices,[12] at least in market-based systems, energy conservation is incentivized. Conversely, depending on their implementation, technology-specific policies may even lower the costs of energy-intensive goods—e.g., by lowering prices on the wholesale markets for electricity, as occurred with renewable energies—effectively increasing demand for them. Such side effects should be considered carefully.

Fifth, the empirical evidence of carbon pricing with respect to short- and long-term impacts on CO_2 emissions is questioned by some.[1,2] We believe it is too early to make any definite statements on carbon pricing in general, although sectoral emission prices have been effective in some cases.[10] Most carbon pricing schemes have been introduced only quite recently, at relatively low price levels, and they often do not address all domestic CO_2 emissions. Furthermore, the scarce empirical evidence on the effect of carbon prices available does indicate that emissions have been significantly reduced compared to counterfactual scenarios.[9] What (relatively low) carbon prices have so far clearly failed to deliver is a deep decarbonization. However, in our view, the lack of a substantial decline in CO_2 emissions in countries that have implemented carbon prices, often at low levels and for limited sectors, does not provide a good case against carbon pricing but rather highlights the importance of (1) identifying and introducing *additional* measures to realize synergies from a well-designed set of policies to achieve deep decarbonization, (2) identifying carbon price paths that are more likely to meet the Paris Agreement goals, and (3) extending carbon pricing to all sectors. Renouncing carbon pricing limits the scope and impact of climate change mitigation measures. Exploring synergies—and potential trade-offs—with other policies, as well as the identification of compensation measures that increase the political and social acceptability of a comprehensive and disruptive policy package, should become a high priority in research on deep decarbonization.

If we are to succeed in limiting global warming, we will need a sensible mix of policies that foster significant technological innovation in the long run and an efficient allocation of resources in the short run. We will therefore need carbon pricing just as much as targeted support for technology diffusion, command and control regulation, institutional reforms, or targeted-infrastructure investment. To

achieve the ambitious Paris Climate goals in time, we will need them all.

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AUTHOR CONTRIBUTIONS

M.K., J.S., and S.W. conceived the idea together at lunch break and subsequently wrote the article with equal contributions from all.

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COMMENTARY

Renewable Energy Will Not Solve Bitcoin's Sustainability Problem

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INTRODUCTION

Bitcoin was introduced as a "peer-to-peer version of electronic cash," allowing for financial transactions without the need for a financial institution (or trusted third parties in general).[1] Bitcoin's underlying technology, called "blockchain," is a cryptographically secured distributed ledger where these transactions are continuously (and publicly) being recorded. The addition of new (blocks of) transactions happens in a process called "mining," where machines are engaging in a competitive process that involves "scanning for a value that when hashed, such as with SHA-256, the hash begins with a number of zero bits."[1] After a node collects new transactions in a block, a nonce in the block is incremented until a value is found that satisfies the required number of zero bits. The finished block is broadcasted to the rest of the network, where other nodes express their acceptance by building the next block on top of it. The creator of a block is rewarded with new coins, as an incentive to support the network.

In the early days of Bitcoin, mining was done using the central processing units (CPUs) of hardware. By the end of Bitcoin's first year (2009), it was realized that mining could also be done using graphic processing units (GPUs). Just like repetitively generating hashes in mining, video processing is a lot of repetitive work. To this purpose, GPUs are equipped with more arithmetic logic units (ALUs) than CPUs. The same ALUs are used in Bitcoin mining to generate SHA-256 hashes. As a result, GPUs mine Bitcoin faster than CPUs. Not long after (2011), miners started to shift to field programmable gate arrays (FPGAs). Then, in 2013, miners started using application-specific integrated circuits (ASICs)